PASSIVE BALANCER FOR EIGHT CELL BATTERY LIFEPO$_4$ PACK

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Abstract: This Article deals with the passive balancer that is required in all multi-cell battery systems. The balancer is designed for eight LiFePo$_4$ battery cells that are connected in series, to achieve the required voltage of about 28 V. Each cell has a capacity of about 9600 mAh, resulting in a 80 Ah battery back. The balance algorithm is performed by main STM32 microcontroller (MCU), which controls eight balancing transistors. For measuring battery cell voltages, there are two variants of cell measurement. The first alternative of cell measurement is a battery monitor IC, which is also capable of low side current measurement and as protection it also drives the low side current transistor switch, which protects powered device. Other options are measurement by 14-bit analog to digital converter (ADC) or with internal ADC of MCU. The balancer circuit also includes an RS485 interface for communication with other devices.

Keywords: Balancer, Battery, Passive Balancer, Active Balancer, Voltage measurement, Current measurement

1 INTRODUCTION

With expansion of electric vehicles, where lithium-based cells are used there is also need for balancing circuits. In order to get the most similar parameters of individual cells, it is necessary to use cells from the one single manufacturer. However, even cells from one manufacturer do not guarantee identical cell parameters. There is always difference in cell resistance and in the state of charge (SOC). If the multi-cell battery pack is not balanced, it results in reduced capacity, lifetime and also reduced device safety where balancer is not used. The balancer ensures equalized voltage across all cells. If the pack is charged without the balancer, the cells are not charged evenly and if this charging and discharging process is repeated, the cells become unbalanced and the voltage of each cell is different. There are two types of balancing circuits. The first category is the passive cell balancer that uses resistors and transistors as a switch to discharge the cell with a higher voltage level to resistor. The second category is the active balancer, where a higher voltage cell is discharged to another cell with a lower capacity and thus equalises the voltage levels. Both types of these balancing circuits have some disadvantages. The first one is inefficient and the second one has difficulties in circuit design. It depends on the application that is more suitable for use.

Any battery powered device that requires higher voltage the cells must be connected in series which implies that the balancing circuit is required. Without balancing of these cells, the lifetime and health of battery pack decreases. Most importantly, cell balancing circuits are needed because of safety reasons. Every battery packs must be equipped with protective circuits due to the overvoltage which can cause thermal damage to the pack and to the device that is powered. Also the undervoltage can cause damage to cell and it could not be charged again. The imbalance of cells causes incomplete use of battery pack and also incomplete charge of battery pack. All these problems can be resolved with balancing circuits, because balancer is also a battery monitoring circuit. The balancing algorithm is different for all types of the batteries.

The comparison of passive and active cell balancing circuits for lithium-based cells was presented in [1]. The better efficiency of the active cell balancing circuit was proven and the power dissipated was decreased with active cell balancing circuit. Article [2] presented the best applications of balancing methods for electric vehicles (EV). The advantages and disadvantages of charge shunting, shared transformer and dissipative method were described. The dissipative balancing method of balancing achieved the best results compared to cost and efficiency. A prototype of passive balancing system for 88 cell battery system with master and slave modules was described [3], where EV suitability was demonstrated. The use of $LiFePO_4$ batteries in battery energy storage system (BESS) was described and importance and effect of imbalance to BESS was presented in [4]. The optimal balancing algorithm was chosen, which was based on SOC and the mid SOC of cells was chosen as balancing point. As a result of the cells not being perfectly balanced and the SOC difference being eliminated and more effective than frequently SOC alignment, the SOC is maintained within a safety range [5].

2 MAIN ARCHITECTURE

As mentioned before, the balancing circuit was designed as a development board where every measurement is duplicated to find the best solution for this application. Main components of this circuit are MOSFET transistors that have connected resistor in drain. The value of resistor is 4.7 Ω and its power dissipation rating is 5 W. The transistor is controlled with STM32 MCU without any gate drivers because there is no need to minimise of drain-source on resistance ($R_{DS(ON)}$). Thus, the voltage level of the driving pulse is 3.3 V. There is only 10 Ω resistance connected in series to decelerate the rising edge of square pulse from MCU. Every transistor with resistor is connected in parallel to each cell.

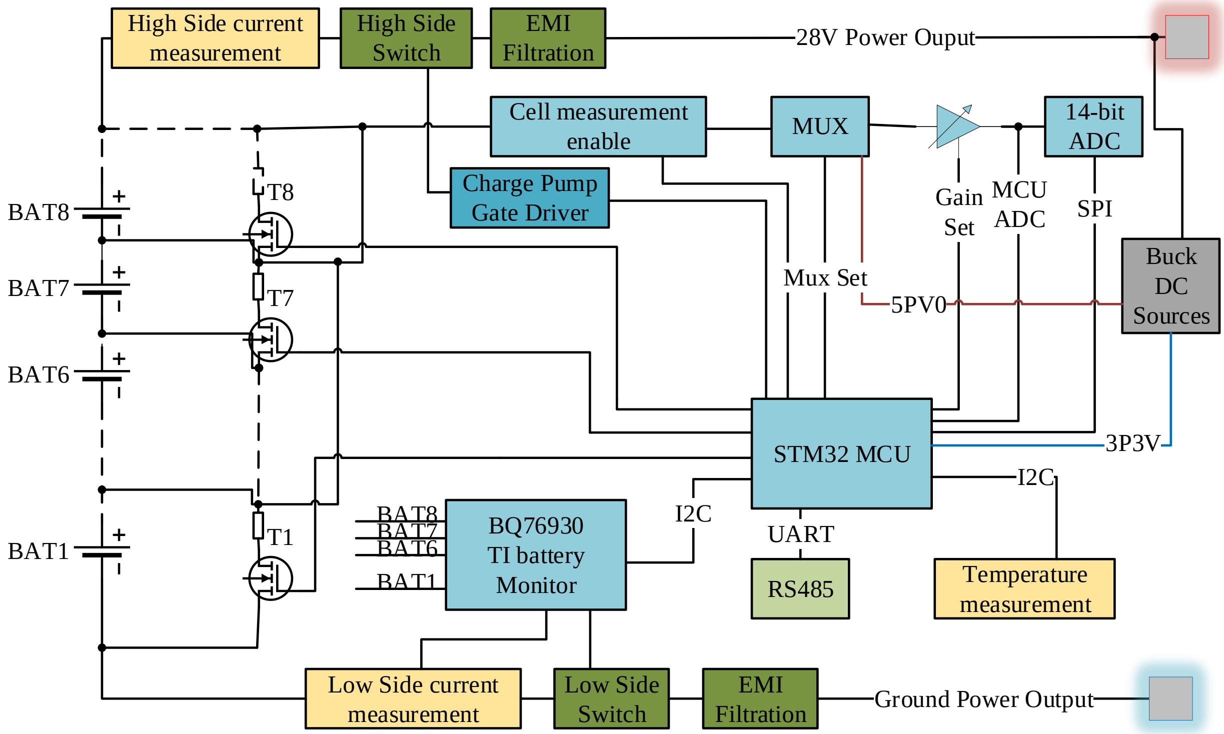

Fig. 1 Block scheme of passive balancer circuit

The main control component is STM32 MCU used as shown on Fig. 1. The MCU controls all measuring and power components. The MCU enables individual cell voltage measurement, controls main high side switch, measures temperature, adjusts the amplifier gain and provides communication through RS485 interface. The protection of connected device to battery is controlled by main high side switch in configuration as bidirectional switch composed of two transistors.

These transistors have their own gate driver, which increases the gate voltage. The driver is designed as charging pump with only few external components and the pump is capable to increase 3.3 V MCU voltage level to 10 V. This leads to decrease transistor's $R_{DS(ON)}$ from 10 mΩ to 2.5 mΩ. The low side switch is controlled by external monitoring circuit BQ76930 [6], whose registers are set with help of MCU. With the registers the maximum output current and other desired protection functions can be set.

The current measurement is ensured by high and low side measurements. Current measurement in low side is ensured by a battery monitor having a bidirectional current measurement amplifier implemented inside and shunt resistor connected externally. Low side measurement is also provided by measurement IC, which sends actual current value to MCU via I^2C. The last type of measurement is situated at high side potential. This measurement is with shunt resistor. The voltage drop is amplified by operational amplifier and this voltage is also measured by internal ADC of MCU. Operational amplifiers differentially measure the voltage drop caused by the charging and also discharging current and the output voltage of these amplifiers is calculated to value that will not exceed maximum input voltage of the internal ADC. For protection, the Zener diode with of 3.3 V Zener voltage is connected in parallel.

As the main cell voltage monitoring is used monitoring circuit BQ76930, which can also be configured as a balancing circuit, but in this application is only exploited as monitoring circuit due to absolute need of balancing control. This circuit needs only one external series resistor and one external capacitance to measure cell voltage. The individual cell voltages are continuously sent to MCU by I^2C interface. As already mentioned, it has many protection features, such as overcurrent protection, short circuit detection, alert interrupt through I^2C, as well as an internal low drop regulator (LDO) to power the MCU and other 3.3 V logic devices. The monitoring circuit can handle up to 10 cells, but in this application the circuit is modified to work with only 8 cells. The voltage is measured by 14 - bit ADC with voltage scale up to 6.275 V and measured every 50 ms. Total update of cells values is 250 ms.

Another option of voltage measurement of individual cells is MUX and external ADC. Every cell voltage is enabled by MCU, which opens and closes N-channel MOSFET below which is connected voltage divider. The divider consists of two high tolerance resistors which divides cell voltage by 10. The divided voltage is brought into input of 8:1 multiplexer (MUX). The multiplexer is controlled by MCU, where it has 3 parallel input pins for input choice. After MUX is connected variable gain amplifier. The gain is set from 1 to 10, depending on the total voltage of individual cells. This amplifier is used in order to increase the accuracy of voltage measurement. A 14-bit analog to digital converter with precision 3.3 V voltage reference circuit is connected at the output of amplifier. The measured data are sent to MCU via SPI. It is possible to measure amplified voltage for data measurement directly with the internal 12-bit ADC of MCU. Total output voltage is measured before main bidirectional switch by differential amplifier and it is also connected directly to another ADC in the MCU.

Each heating part is controlled by a temperature sensor to avoid thermal error. High side bidirectional switch, low side switch and two sides of power balancing resistors have their own current sensor. Moreover, these temperature sensors have their own I^2C bus, due to bus overload, where the ADC and the monitoring circuit are connected.

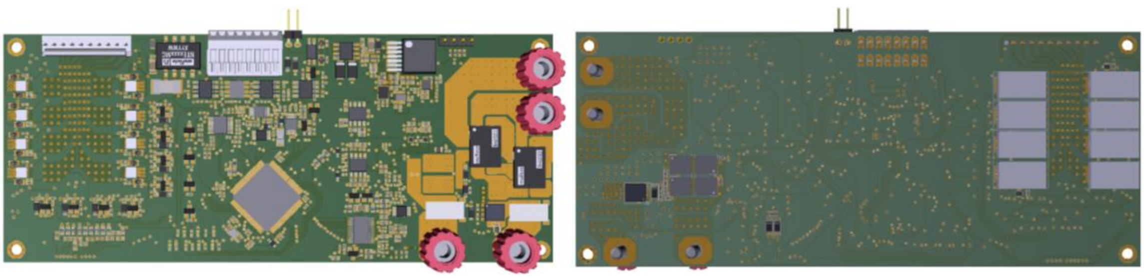

Fig. 2 Top and bottom view of balancing circuit

3 CELL BALANCING ALGORITHM

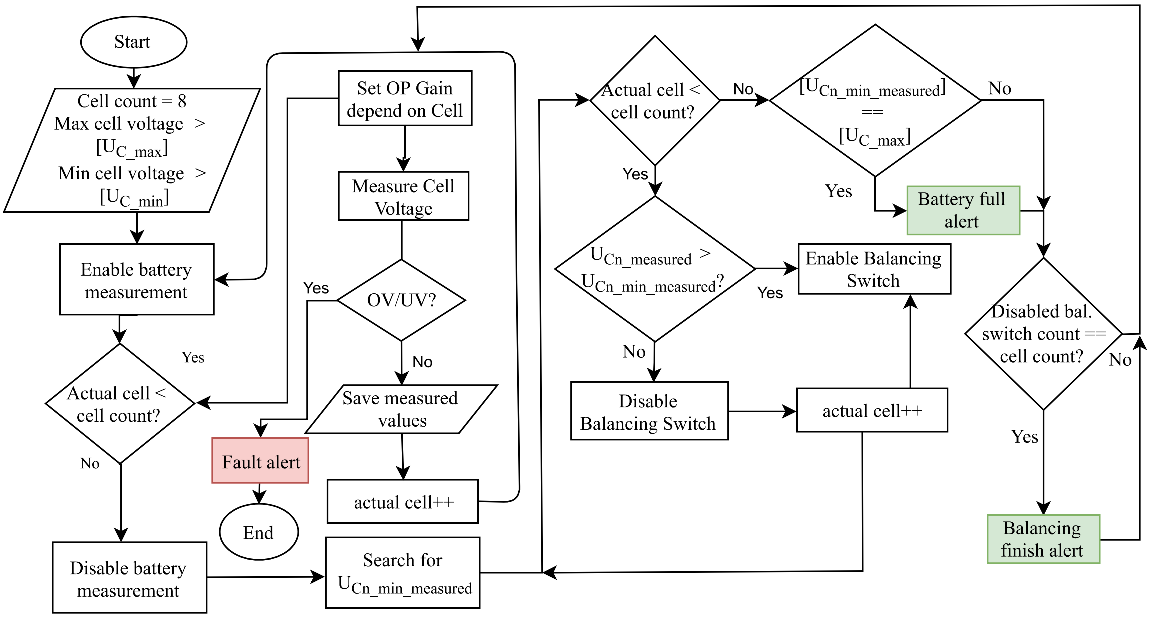

Fig. 3 Flowchart of used cell balancing algorithm

The balancing algorithm process is described in Fig. 3. It is divided into two parts. The left part is focused on voltage cell measurement and the right part is focused on balancing algorithm. As usual, there is start condition which that follows with definition of cell number, the maximum acceptable cell voltage U_{Cn_max}, minimum allowable cell voltage U_{Cn_max}. After the cell measurement is enabled, gain of operational amplifier is set and the voltage is measured by the ADC. Overvoltage and undervoltage thresholds are evaluated. If this there is cell undervoltage or overvoltage detected the fault alert occurs. This measurement is repeated for all cells and when all cells are measured, the balancing part of this flowchart begins. As first is the actual measured cell value is compared to the cell voltage with the lowest voltage level. If this level is exceeded, the balancing switch is enabled, and this process starts again. The battery is fully charged when the minimum measured cell voltage ($U_{Cn\_min\_measured}$) is consistent with maximum cell voltage U_{Cn_max}. When the disabled balancing switches are equal to the actual cell count, the balancing is completed, and the process begins with voltage measurement again.

4 PASSIVE AND ACTIVE BALANCING RESULTS

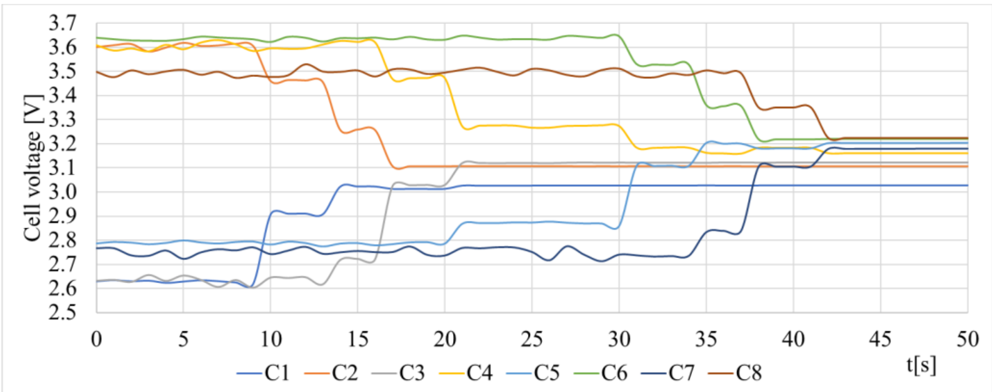

Fig. 4 Measured cell voltage with active balancing circuit

Fig.4 shows the principle of active cell balancer. Data shown at chart were measured with development kit of active balancer. At graph is shown how for example cell C1 is charged with cell C2 etc.

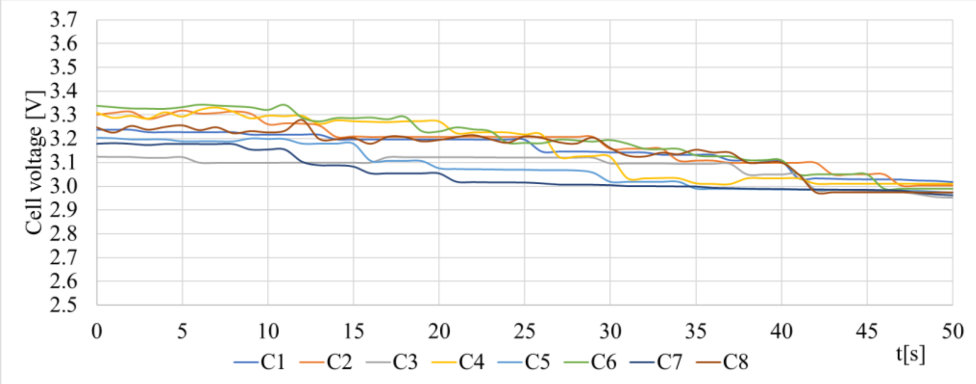

Fig. 5 Measured cell voltage with passive balancer

Fig. 5 shows how passive balancer presented in this article discharges the cells to one voltage level set to 3 V. Data shown in graph were measured with testing balancing algorithm.

5 CONCLUSION

This article presents basic knowledge of passive and active balancers. More attention is paid to the designed passive balancer and its main components. Voltage cell measurement options as well as high and low current measurements for bidirectional current have been described. Final balancing curves for both types of amplifiers were presented. The main advantage of this balancer is the reduction in size and possibility to control of all aspects of balancing against commercially available balancing circuits. The balancer is ready for eight and fewer cells and can be used for a variety of cell chemistry. Also, this balancer is capable to handle currents up to 50 A and the hot swap function can be implemented when two battery packs and two of these balancing circuits are used.

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